Benefits of Horizontal Cooperation in Supply Chains

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Introduction

➠ **Horizontal cooperation** is *"an active cooperation between two or more firms that operate* on the same level *of the supply chain and perform a comparable logistics function". (Cruijssen et al., 2006)*

➠ **Henkel, Colgate and Reckitt Benckiser**: 800,000 pallets per year and a unique warehouse.

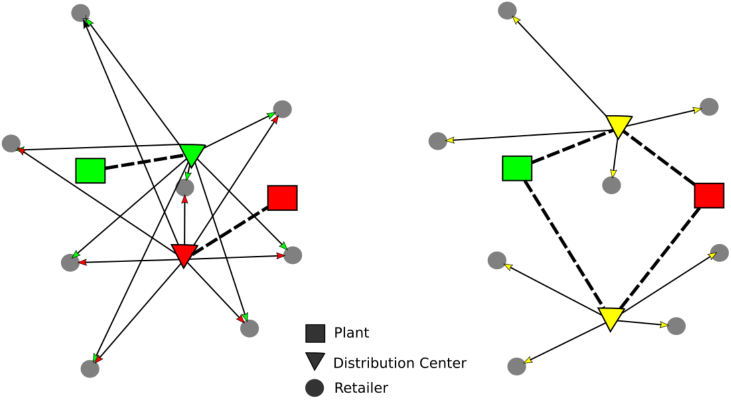
- The vehicle loading rate improved from 75% to 95%.
- The number of trips reduced by 20% (about 800 trucks/year).
- The inventory reduced by 20%.

➠ **Procter&Gamble and Tupperware**: to improve the cargo density (weight and volume) between Belgium and Greece.

- Reduction of 17% on total transportation costs.
- 150,000 truck-km and 200 tons of CO_2 saved in the first year.

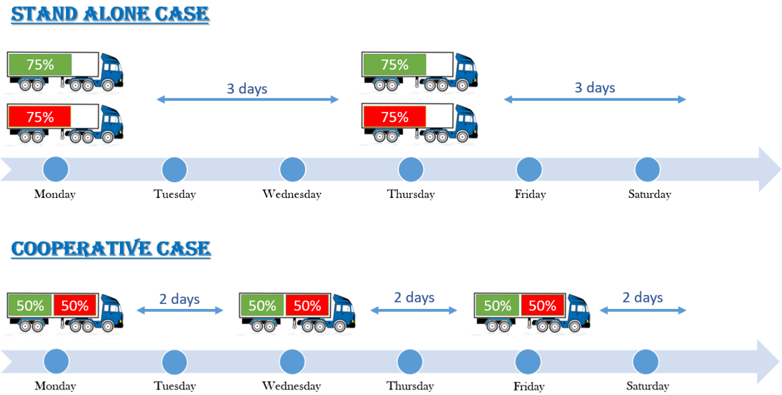
➠ Horizontal cooperation offers several **benefits**.

Benefit 1: More DCs and Shorter Distances



1. Access to more, better positioned, DCs.
2. But typically less DCs in total.
3. Leading to shorter distances (cost and CO_2).
4. And shorter lead time (proportional to distances).

Benefit 2: Improved Vehicle Loading



1. Improved vehicle loading rate.
2. Lower number of deliveries (reduced transportation cost).
3. Higher delivery frequency (but less vehicles coming).
4. Lower inventory level at retailers.

Barriers to Horizontal Cooperation

➠ A first barrier to cooperation is the **assessment of benefits**.

1. **Cost** reductions go from 5% to about 30% (Hageback and Segerstedt, 2004; Frisk et al., 2010).
2. Also a high variation in the **emissions** reductions due to cooperation, between 8% and 33% (Soysal et al., 2018).

➠ The cooperation requires **confidence, trust, and information sharing** between the partners involved in the process.

➠ A fair **gain sharing** mechanism is essential.

➠ Cooperative solutions should take into account the **individuality** and the expectations of each partner.

Research Objectives

➠ Our main objective is to present valuable managerial insights to help companies **assessing the potential economical and environmental benefits** they can get when cooperating with specific partners, **as a function of their characteristics.**

➠ Specifically, we study the impact of:

1. The operating **costs** (DC opening, ordering, holding costs).
2. The **market** (demand variability, geographical distribution).
3. The **partners** (number of partners, partners' expectations).

➠ We use a **location-inventory model** to decide the locations of the DCs, the delivery network, and the inventory decisions.

In this **presentation**, we present three related papers.

Assessing the Benefits of Horizontal Cooperation using a Location-Inventory Model

Thomas Hacardiaux, Jean-Sébastien Tancrez

- Hacardiaux, T., Tancrez, J. S. (2018). Assessing the benefits of horizontal cooperation using a location-inventory model. CORE DP No. 2018014. Université catholique de Louvain, Center for Operations Research and Econometrics.
- Under revision for **Operational Research Journal**

Location-Inventory Model

We assess the cooperation **benefits** from sharing a joint supply network, and the impact of partners and market characteristics.

$$\min \sum_{d} F_d\, y_d + \sum_{d,r} T\, D_{dr}\, \frac{\Lambda_r}{Q_{dr}}\, x_{dr} + \sum_{d,r,i} H_r^i\, \frac{Q_{dr}}{2}\, \frac{\lambda_r^i}{\Lambda_r}\, x_{dr}$$
$$+ \sum_{d,i} \sqrt{2\, K_d^i\, h_d^i}\, v_{1d}^i + \sum_{d,r,i} H_r^i\, z_\alpha\, \sigma_r^i\, \sqrt{LT_{dr}}\, x_{dr} + \sum_{d,i} h_d^i\, z_\alpha\, \sqrt{LT_d^i}\, v_{2d}^i$$

$$\begin{aligned} s.t. \quad & \sum_r \lambda_r^i\, (x_{dr})^2 \leq (v_{1d}^i)^2 && \forall d, i \\ & \sum_r (\sigma_r^i)^2\, (x_{dr})^2 \leq (v_{2d}^i)^2 && \forall d, i \\ & \sum_d x_{dr} = 1 && \forall r \\ & x_{dr} \leq y_d && \forall d, r \\ & v_{1d}^i, v_{2d}^i \geq 0 \;\; ; \;\; x_{dr}, y_d \in \{0,1\} && \forall i, d, r \end{aligned}$$

➠ *Transportation costs are proportional to the number of vehicles (not flow).*

Research Objective and Experiments

1. We **assess the cooperation benefits** of a joint supply network, integrating **location decisions** and **inventory decisions** (and demand uncertainty).

2. We perform **27,180 experiments** to reinforce the validity of our results, varying several key parameters.
    - Facility opening cost,
    - Vehicle capacity,
    - Inventory holding cost,
    - Ordering cost,
    - Demand variability,
    - Market size (distances),
    - Number of partners.

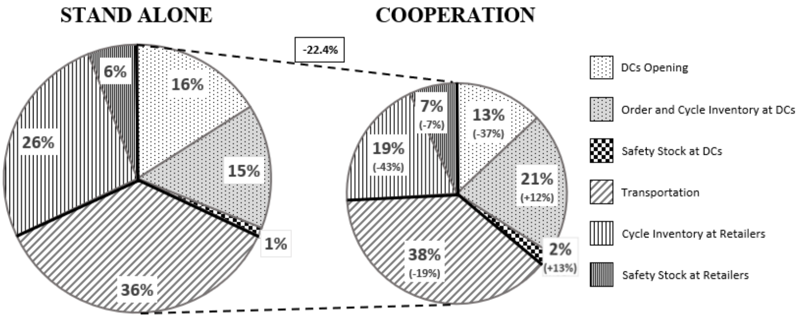
Synergy Value

➠ The average (relative) benefit is around 22.4%.

F	C	CV = 0,4			CV = 1			Average
		H = 0,25	H = 0,5	H = 1	H = 0,25	H = 0,5	H = 1	
1000	10%	19.70% 5.20|3.23 0.94|0.97	14.86% 6.23|4.27 0.95|0.98	15.87% 7.37|4.87 0.96|0.99	18.95% 5.17|3.37 0.94|0.97	16.80% 6.50|4.10 0.95|0.98	**14.73%** 7.77|5.03 0.96|0.99	16.82% 6.37|4.14 0.95|0.98
1000	40%	21.91% 3.77|2.53 0.86|0.92	20.85% 4.87|3.00 0.85|0.93	19.09% 5.83|3.60 0.86|0.94	21.19% 3.37|2.50 0.86|0.92	19.76% 4.93|3.13 0.85|0.93	17.50% 6.03|3.77 0.86|0.95	20.05% 4.80|3.09 0.86|0.93
1000	70%	23.60% 3.73|1.93 0.75|0.89	22.61% 4.23|2.50 0.74|0.88	21.11% 5.20|3.00 0.75|0.89	22.68% 3.13|1.97 0.75|0.87	21.47% 4.30|2.63 0.74|0.88	19.37% 5.60|3.10 0.74|0.89	21.81% 4.36|2.52 0.75|0.88
1000	100%	25.55% 3.53|1.50 0.54|0.72	24.46% 4.07|1.97 0.51|0.71	23.07% 4.80|2.27 0.50|0.70	24.34% 2.90|1.60 0.53|0.70	23.03% 4.10|2.17 0.50|0.68	21.00% 5.23|2.70 0.50|0.68	23.57% 4.11|2.03 0.51|0.70
4000	10%	20.54% 2.13|1.03 0.97|0.99	18.82% 2.00|1.57 0.97|0.98	19.11% 2.23|2.33 0.97|0.98	19.88% 2.03|1.10 0.97|0.98	18.13% 2.00|1.67 0.97|0.98	18.33% 2.43|2.37 0.96|0.98	19.14% 2.14|1.68 0.97|0.98
4000	40%	26.11% 2.20|1.07 0.88|0.96	23.70% 2.17|1.13 0.89|0.97	22.00% 2.00|1.33 0.90|0.95	25.18% 2.10|1.00 0.88|0.96	22.47% 2.03|1.10 0.89|0.97	20.52% 2.07|1.43 0.89|0.95	23.33% 2.09|1.18 0.89|0.96
4000	70%	28.85% 2.20|1.00 0.78|0.93	26.62% 2.33|1.00 0.78|0.93	24.62% 2.07|1.13 0.79|0.92	27.80% 2.40|1.00 0.78|0.93	25.17% 2.20|1.00 0.78|0.93	22.78% 2.00|1.20 0.79|0.91	25.97% 2.20|1.06 0.78|0.92
4000	100%	**30.62%** 2.40|1.20 0.58|0.79	28.63% 2.33|1.00 0.55|0.77	26.70% 2.10|1.10 0.56|0.76	29.57% 2.40|1.33 0.56|0.78	27.06% 2.33|1.07 0.55|0.77	24.60% 2.03|1.07 0.56|0.75	27.86% 2.27|1.13 0.56|0.77
Average		24.61% 3.15|1.69 0.79|0.89	22.57 3.53|2.05 0.78|0.89	21.45% 3.95|2.45 0.78|0.89	23.70% 2.94|1.73 0.78|0.89	21.74% 3.55|2.11 0.78|0.89	19.85% 4.15|2.58 0.78|0.88	**22.40%** 3.55|2.10 0.78|0.89

Cooperation Benefits

- The cooperation benefits come from:
  1. **Shared DCs**, their total number is reduced.
  2. **Transportation**, reduced distances, efficient vehicle loading.
  3. **Retailers cycle inventory**, more frequent deliveries.
  4. **Retailers safety stocks**, reduced lead times.
- But, **inventory at DCs and ordering** costs increase.



Conclusion - Managerial Insights (1/2)

- We find an average synergy value of **22.4%** (14.7% to 30.6%).
  1. **Companies open 2.10 DCs** on average (1.77 DCs for each stand-alone company), reducing distances by 10.5%.
  2. Cooperation allows to **improve the average vehicle loading rate, by 11%** on average (from 78% to 89%).

- Companies have **stronger incentives** to cooperate when:
  1. Opening costs are high.
  2. Companies have large inefficiently loaded vehicles.
  3. Companies transport small cheap products.
  4. Order cost is low.
  5. The demand variability is low.

Conclusion - Managerial Insights (2/2)

➠ The impact of cooperation **for retailers** is significant:

1. **Inventory cost** is reduced by 43%.
2. The **delivery frequency** for a product is doubled.
3. **Less vehicles** come to the retailer's door.

➠ The addition of new partners allows an increase of the average benefits to **31.2%** and **36%** with 3 and 4 partners, respectively.

➠ **The possibility to close DCs is more critical**, while the option to open DCs is less impactful for the success of the collaboration.

Assessing the Environmental Benefits of Horizontal Cooperation using a Location-Inventory Model

Thomas Hacardiaux, Jean-Sébastien Tancrez

Hacardiaux, T., Tancrez, J. S. (2020). Assessing the environmental benefits of horizontal cooperation using a location-inventory model. **Central European Journal of Operations Research**, 28(4), 1363-1387.

Objectives' priority

The assessment of the possible CO_2 emissions reductions as an additional **motivation to cooperate** horizontally.

When deciding on the **supply network design**, the focus is given on **cost reduction**.

As our model provides the traveled distances and the loading rate of the vehicles (shipment sizes), it allows to apply the $\boldsymbol{CO_2}$ **emissions computation** a posteriori (Pan et al., 2013).

$$\epsilon^{v}_{dr} = \epsilon^{ve}\frac{\Lambda_r}{Q_{dr}} + (\epsilon^{vf} - \epsilon^{ve})\frac{\Lambda_r}{C_{dr}}$$

➠ If the carried quantity doubles, the emissions **less than double**.

Conclusion - Managerial Insights (1/2)

➠ We observe an **average CO_2 emissions reduction of 16.3%**, showing the significant environmental benefits that horizontal cooperation can bring.

➠ However, **the reductions vary significantly**, ranging from 0.2% and 35.9%.

➠ The reduction in CO_2 emissions comes from **two main factors**:

1. Sharing their distribution centers reduces the average **distance to the retailers by 10.5%**.
2. Sharing vehicles improves the average **vehicle loading rate by 11%**, and leads to a reduction in the total **number of trips per period by 12.5%** on average.

Conclusion - Managerial Insights (2/2)

	F_d	$Cap\%$	K_d	$H_d^i = H_r^i$	$Width$	CV	$\#Partners$
Comparison	1000|4000	10|100	250|1000	0.25|1	500|1000	0.4|1	2|4
CO2 Emissions	-8.2%	+3.9%	-5.5%	+3.6%	+3.9%	+0.7%	+14.5%
Logistic Cost	+3.5%	+7.1%	-3.1%	-3.1%	+0.5%	-1.2%	+13.4%

➠ The horizontal cooperation is **more environmentally profitable if**:

1. Low facility opening costs;
2. Unsuited vehicle capacity;
3. Low order costs;
4. Expensive products;
5. Vast market;
6. High demand variability;
7. High number of partners (28.7% and 33.8% with 3 and 4 partners).

Balancing partner preferences for logistics costs and carbon footprint in a horizontal cooperation

Thomas Hacardiaux, Christof Defryn, Jean-Sébastien Tancrez, Lotte Verdonck

- Hacardiaux, T., Defryn, C., Tancrez, J-S., Verdonck, L. (2020). Balancing partner preferences for logistics costs and carbon footprint in a horizontal cooperation. Maastricht University, Graduate School of Business and Economics. GSBE Research Memoranda, No. 002.
- Under revision for **OR Spectrum Journal**

Individuality of partners

➠ **Observation:** companies with different (potentially conflicting) preferences could **improve their individual outcome by diverging** from the joint solution.

➠ **Contributions:**

1. First, we develop a multi-objective framework accounting for the **individuality of partners** in terms of their **costs-emissions** preferences and their **influence** weights.
2. Second, we propose new approaches for **solving our multi-objective multi-partner model**; two approaches resulting in **Pareto fronts** and three approaches defining **unique solutions**.

➠ **Consequently**, all stakeholders should be more likely to **accept the solution**, and the **long-term viability** of the collaboration is improved.

Location-Inventory Model

A multi-objective and multi-partner model with $2n_I$ objectives.

$$\min \quad \frac{\Lambda^i}{\Lambda} \sum_d F\, y_d + \sum_r \frac{\lambda_r^i}{\Lambda_r} \sum_d T\, D_{dr}\, \frac{\Lambda_r}{Q_{dr}}\, x_{dr} + \sum_{d,r} H_r^i\, \frac{Q_{dr}}{2}\, \frac{\lambda_r^i}{\Lambda_r}\, x_{dr}$$

$$+ \sum_d \sqrt{2\, K_d^i\, h_d^i}\, v_{1d}^i + \sum_{d,r} H_r^i\, z_\alpha^i\, \sigma_r^i\, \sqrt{LT_{dr}}\, x_{dr} + \sum_d h_d^i\, z_\alpha^i\, \sqrt{LT_d^i}\, v_{2d}^i \qquad \forall \boldsymbol{i}$$

$$\min \quad \sum_r \frac{\lambda_r^i}{\Lambda_r} \sum_d \left[\epsilon^e \frac{\Lambda_r}{Q_{dr}} + (\epsilon^f - \epsilon^e) \frac{\Lambda_r}{C}\right] D_{dr}\, x_{dr} \qquad \forall \boldsymbol{i}$$

$$
\begin{aligned}
s.t. \qquad \sum_r \lambda_r^i\, (x_{dr})^2 &\le (v_{1d}^i)^2 && \forall d, i \\
\sum_r (\sigma_r^i)^2\, (x_{dr})^2 &\le (v_{2d}^i)^2 && \forall d, i \\
\sum_d x_{dr} &= 1 && \forall r \\
x_{dr} &\le y_d && \forall d, r \\
v_{1d}^i, v_{2d}^i &\ge 0 && \forall d, i \\
x_{dr}, y_d &\in \{0, 1\} && \forall d, r
\end{aligned}
$$

Two approaches resulting in Pareto fronts

$$\min \quad \frac{\Lambda^i}{\Lambda} \sum_d F\, y_d + \sum_r \frac{\lambda_r^i}{\Lambda_r} \sum_d T\, D_{dr} \frac{\Lambda_r}{Q_{dr}} x_{dr} + \sum_{d,r} H_r^i \frac{Q_{dr}}{2} \frac{\lambda_r^i}{\Lambda_r} x_{dr} + \sum_d \sqrt{2\, K_d^i\, h_d^i}\, v_{1d}^i$$

$$+ \sum_{d,r} H_r^i\, z_\alpha^i\, \sigma_r^i \sqrt{LT_{dr}}\, x_{dr} + \sum_d h_d^i\, z_\alpha^i \sqrt{LT_d^i}\, v_{2d}^i \qquad \forall \boldsymbol{i}$$

$$\min \quad \sum_r \frac{\lambda_r^i}{\Lambda_r} \sum_d \left[\epsilon^e \frac{\Lambda_r}{Q_{dr}} + (\epsilon^f - \epsilon^e) \frac{\Lambda_r}{C}\right] D_{dr}\, x_{dr} \qquad \forall \boldsymbol{i}$$

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$$+ \sum_{d,r} H_r^i\, z_\alpha^i\, \sigma_r^i \sqrt{LT_{dr}}\, x_{dr} + \sum_d h_d^i\, z_\alpha^i \sqrt{LT_d^i}\, v_{2d}^i \qquad \forall \boldsymbol{i}$$

$$\min \quad \sum_r \frac{\lambda_r^i}{\Lambda_r} \sum_d \, [\epsilon^e \frac{\Lambda_r}{Q_{dr}} + (\epsilon^f - \epsilon^e) \frac{\Lambda_r}{C}]\; D_{dr}\; x_{dr} \qquad \forall \boldsymbol{i}$$

➠ **Approach 1: Articulation at the coalition level**

$$\min \quad \sum_d F\, y_d + \sum_{d,r} T\, D_{dr} \frac{\Lambda_r}{Q_{dr}} x_{dr} + \sum_{d,r,i} H_r^i \frac{Q_{dr}}{2} \frac{\lambda_r^i}{\Lambda_r} x_{dr} + \sum_{d,i} \sqrt{2\, K_d^i\, h_d^i}\, v_{1d}^i$$

$$+ \sum_{d,r,i} H_r^i\, z_\alpha^i\, \sigma_r^i \sqrt{LT_{dr}}\, x_{dr} + \sum_{d,i} h_d^i\, z_\alpha^i \sqrt{LT_d^i}\, v_{2d}^i$$

$$\min \quad \sum_{d,r} \, [\epsilon^e \frac{\Lambda_r}{Q_{dr}} + (\epsilon^f - \epsilon^e) \frac{\Lambda_r}{C}]\; D_{dr}\; x_{dr}$$

Two approaches resulting in Pareto fronts

$$\min \quad \frac{\Lambda^i}{\Lambda} \sum_d F\, y_d + \sum_r \frac{\lambda_r^i}{\Lambda_r} \sum_d T\, D_{dr} \frac{\Lambda_r}{Q_{dr}}\, x_{dr} + \sum_{d,r} H_r^i \frac{Q_{dr}}{2} \frac{\lambda_r^i}{\Lambda_r}\, x_{dr} + \sum_d \sqrt{2\, K_d^i\, h_d^i}\, v_{1d}^i$$

$$+ \sum_{d,r} H_r^i\, z_\alpha^i\, \sigma_r^i \sqrt{LT_{dr}}\, x_{dr} + \sum_d h_d^i\, z_\alpha^i \sqrt{LT_d^i}\, v_{2d}^i \qquad \forall \boldsymbol{i}$$

$$\min \quad \sum_r \frac{\lambda_r^i}{\Lambda_r} \sum_d \left[\epsilon^e \frac{\Lambda_r}{Q_{dr}} + (\epsilon^f - \epsilon^e) \frac{\Lambda_r}{C}\right] D_{dr}\ x_{dr} \qquad \forall \boldsymbol{i}$$

➠ **Approach 2: Articulation at the partner level**

$$min \quad \frac{\Lambda^i}{\Lambda} \sum_d F\, y_d + \sum_{d,r} T\, D_{dr} \frac{\lambda_r^i}{Q_{dr}}\, x_{dr} + \sum_{d,r} H_r^i \frac{Q_{dr}}{2} \frac{\lambda_r^i}{\Lambda_r}\, x_{dr} + \sum_d \sqrt{2\, K_d^i\, h_d^i}\, v_{1d}^i$$

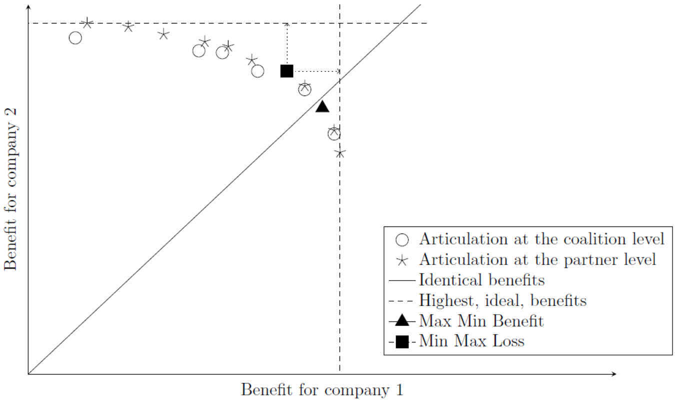
$$+ \sum_{d,r} H_r^i\, z_\alpha^i\, \sigma_r^i \sqrt{LT_{dr}}\, x_{dr} + \sum_d h_d^i\, z_\alpha^i \sqrt{LT_d^i}\, v_{2d}^i + \boldsymbol{\beta^i} \sum_{d,r} \left[\epsilon^e \frac{\lambda_r^i}{Q_{dr}} + (\epsilon^f - \epsilon^e) \frac{\lambda_r^i}{C}\right] D_{dr}\, x_{dr}$$

$$\forall \boldsymbol{i}$$

Partners benefits

➠ We obtain two **sets of Pareto-optimal solutions** that can support the negotiation and decision-making process.

➠ The Pareto fronts **balance either the logistics costs and CO_2 emissions** or compromise **the partners' augmented costs.**



Identifying unique solutions

Three approaches to highlight a solution

1) Preference articulation at coalition level

Transform the individual preferences (β^i) into a collaborative weight (β) based on the volumes or the augmented costs of partners.

2) Preference articulation at individual level

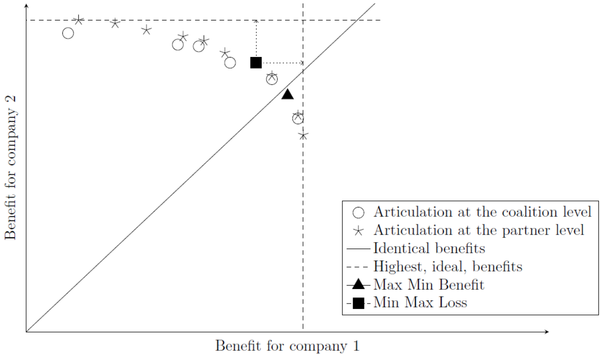
Generate partner's influence weight γ^i which characterize the influence of the companies on the final cooperative solution. To define them, we rely again on demand volumes or the stand-alone augmented costs.

Identifying unique solutions

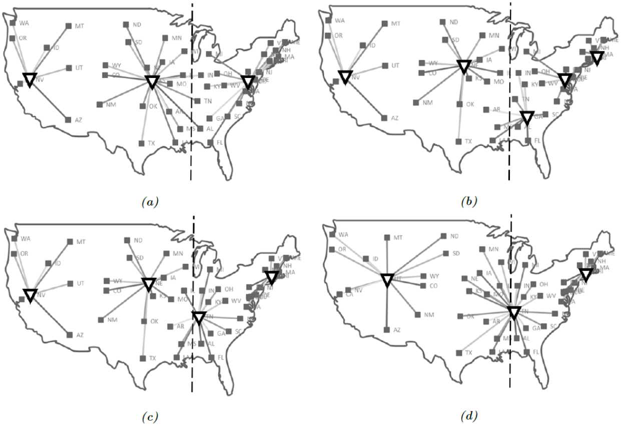
3) Partners benefits approach

Look at the benefits that cooperation generates for the partners individually.

1. Maximizing the minimal partner benefit.
2. Minimizing the maximal partner loss



Different geographical demand distribution



➠ When geographical spread and individual preferences differ, applying **approaches that conserve individual preferences** allows to design a network with **different priorities** in the regions.

Conclusion

➠ Current research considers horizontal logistics collaboration as a **single-objective minimization** of transportation costs, assuming partners agree on **a unique collaborative goal**.

➠ We propose a **multi-objective** and **multi-partner** model including the **individual costs-emissions preferences** and the partners' influence weight in the collaboration.

➠ Collaboration **remains beneficial** for both partners in all cases.

➠ However, preference weight combinations **impact the individual benefits levels** of the partners.

➠ When partners' preferences are different, each company **benefits more from** a reduction of **its non-priority objective**.

General Conclusion

➠ **We assess the benefits of horizontal cooperation.**

1. Minimising the costs.
2. Minimising the costs then the CO_2 emissions.
3. Minimising both objectives at the same time.

➠ We provide **valuable managerial insights** for companies that want to cooperate depending on partners' and markets' characteristics.

➠ We incorporate individual objectives of partners in the model to guaranty **the sustainability** of the collaboration.

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